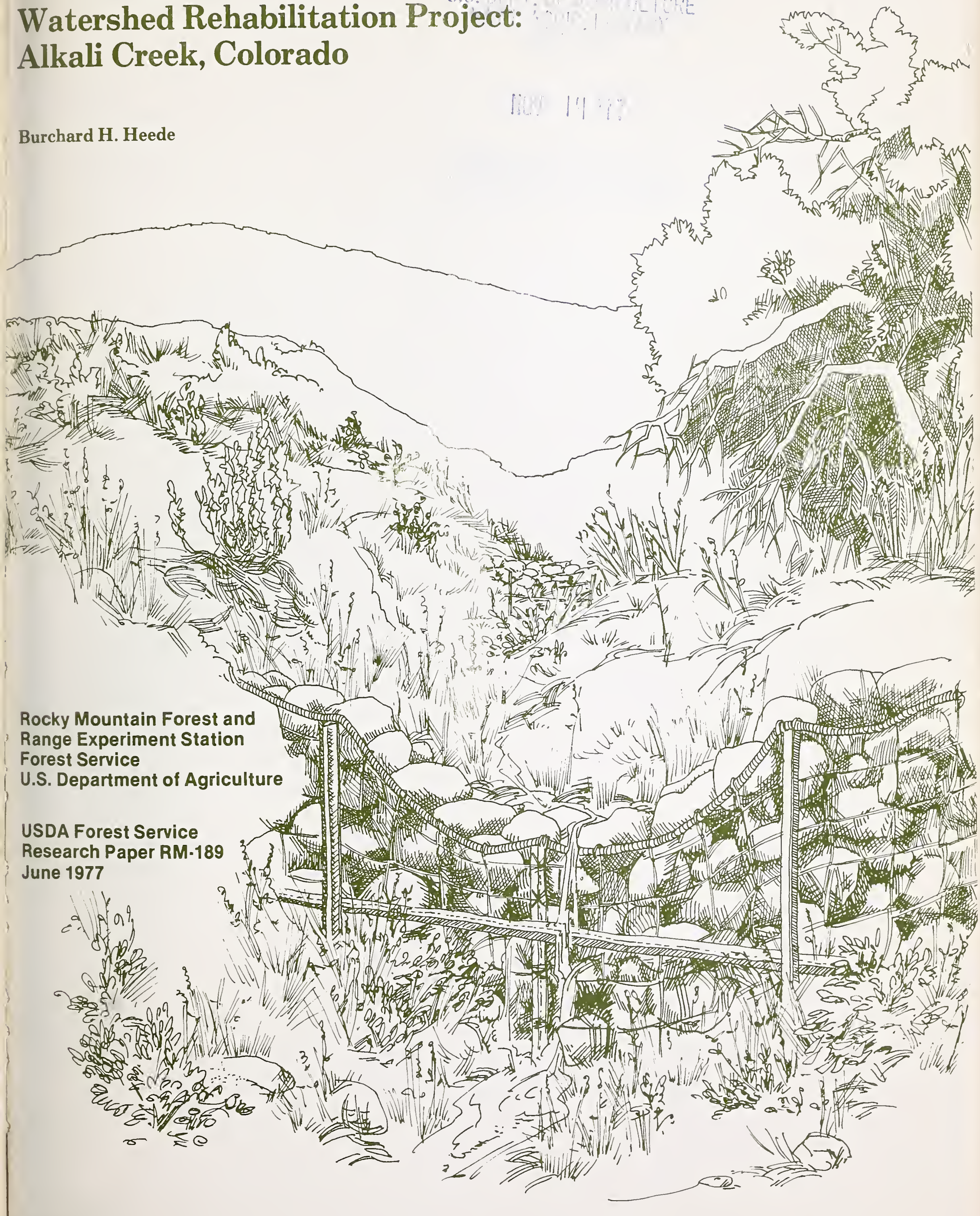
Case Study of a Watershed Rehabilitation Project: Alkali Creek, Colorado

Burchard H. Heede



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Abstract

The headwaters of Alkali Creek watershed were fenced and cattle grazing excluded from 1958 to 1966. In 1963, check dams or vegetation-lined waterways were constructed in about half of the gullies. Seven years later (1970), the ephemeral flow became perennial. Vegetation cover improvement and formation of additional alluvial water reservoirs in the gullies above the check dams are considered to be responsible for this change. Sediment deposits above the dams and luxuriant growth of vegetation enhanced the stabilization processes. Waterways experienced only one-third the net erosion of gullies that were not structurally treated. Stabilization also proceeded in the gullies that were not treated, however. Local base level controls exerted by the structurally treated gullies, as well as overall vegetation improvement, probably caused the stabilization. Untreated gullies outside the project increased their surface area three times more than the untreated gullies inside the project. Both gully groups had comparable morphologic characteristics and belonged to the same stream net. An empirical equation expressed relationships between original gully gradient and deposit gradient above check dams. Thus dam spacing can be calculated for conditions similar to the study area and within the same physiographic region. The overall goal of the treatment was achieved.

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Case Study of a Watershed Rehabilitation Project: Alkali Creek, Colorado[1]

Burchard H. Heede[2]

[1]This study was made in cooperation with the White River National Forest, Glenwood Springs, Colorado.

[2]Principal hydraulic engineer, located at Research Work Unit at Tempe, Arizona, in cooperation with Arizona State University; central headquarters maintained at Fort Collins, in cooperation with Colorado State University.

Contents

ERRATA

Due to a referencing error, some tables were misplaced in Research Paper RM-189. In the second column of page 10, the reference should be to table 2, rather than table 3. Table 3, on page 11, should then be on page 13, in the position occupied by table 4. Table 4 is first referenced in the first paragraph of page 14.

There is also a minor inconsistency between equation 1 on page 11 and the text immediately above it. Channel width at spillway elevation should be symbolized by b_a as in equation 1, rather than by B, as in the text.

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Management Highlights

Rationale

In the 1950's and 60's, watershed restoration was emphasized on the National Forests of the West. Numerous rehabilitation schemes were developed, especially within the States of California, Utah, Wyoming, Colorado, and South Dakota. Alkali Creek watershed in Colorado is an example of one of these schemes. The treatment approach reflects the rationale that it is easiest to control the concentrated flow where it occurs–in gullies or drainage ways. Once the active gullies are controlled, the depleted vegetation cover on the watershed as well as in the gullies can be restored by routine procedures such as seeding. Treatment measures applied were construction of check dams, conversion of gullies to vegetation-lined waterways, and management of vegetation by controlling cattle grazing and planting grass on disturbed sites. In contrast, most other projects concentrated the surface runoff on hillsides in extensive artificial earth structures, such as contour trenches, for later infiltration.

The Alkali Creek project may be unique because of the availability of intensive background data. Pre- and posttreatment conditions were described in detail. Before treatment began, over 20 gullies had been thoroughly surveyed on the mi^2 watershed, and a relatively dense network of eight precipitation gages was installed. The vegetation cover and the soils were sampled before and after treatment.

Overall project objectives were to: (1) rehabilitate the depleted watershed by vegetative and engineering measures, (2) test their combined effectiveness on restoration, and (3) develop new treatment approaches where required.

Results

The evaluation of successes and failures of the restoration project considered the combined effects of all treatment measures. Although it was possible to show changes in vegetation cover, sedimentation, flow, and erosion it was not possible to assign the degree of responsibility for these changes to individual measures.

During 12 project years, check dams accumulated a total of 69,000 ft^3 of sediment, but 44% of all dams (total = 133) had empty catch basins. The sediment deposits above the dams covered extensive gully segments, averaging 65% of gully length. A relationship was apparent between original gully gradients and that of the sediment deposits ($\bar{R}^2 = 0.73$).

Since the dams have effective heights up to 7 ft, gully depths were substantially decreased. This decrease, combined with bank toe stabilization, led to gentler gully side slopes, which allowed vegetation to become established. In spite of one storm of unusually high intensity, not one structure was lost, but annual maintenance was required during the first 4 treatment years.

After 7 treatment years, the ephemeral flow became perennial. A combination of vegetative cover enhancement and sediment deposits was probably responsible for the conversion.

The successful conversion of gullies to vegetation-lined waterways changed the regimen of runoff, which in turn lowered erosion rates to less than 1/5 of those on gullies not structurally treated. An effective vegetative cover became established, which added to the grazing resource. In contrast to the pretreatment condition, the cover consisted of palatable grasses (mainly smooth brome[3] and intermediate wheatgrass).

[3]Common and botanical names of plants mentioned are listed at the end of this paper.

Even gullies that were not structurally treated also improved greatly; annual soil losses during the last 10 treatment years were 78% less than during the first 2 years. These gullies benefited from vegetation management as well as from check dam treatments in other gullies. Improvement was also indicated by an average increase in gully surface area of only 1/3 that of untreated gullies outside the project. Thus, the project gullies that were not directly treated also benefited from the project.

Cattle removal as well as grazing reduction resulted in a bare soil decrease of 12.6% (29.1% to 16.5%) outside the gullies. In the gullies, the perennial flow produced dense mats of vegetation on bottoms, and vegetation moved up the banks. On the watershed, vegetative cover increases were largest in sagebrush (1.5% to 18.8%). In contrast, the perennial grass and forb cover decreased by 27.6% (98.2% to 70.6%).

Soil and water rehabilitation projects of the type installed on Alkali Creek watershed are expensive. We are unable to weigh these costs against the total benefit of the project, however, because socioeconomic evaluations were not included in the study.

The physical on-site benefits indicate that the overall project goals have been achieved. Erosion is still active locally, but stabilization processes continue. We cannot project the final status of stabilization, if such is attainable at all in a dynamic watershed system. High-intensity storms, droughts, or other exceptional events will continue to wear down mountains. We may surmise, however, that—due to perennial flows—the vegetative cover will further increase its effectiveness with time. Exceptional events will temporarily interrupt the stabilization processes.

Recommendations

The soil and water rehabilitation project at Alkali Creek watershed can serve—with modifications—as a blueprint for future projects.

Check dam treatments should be confined to the mainstem gully plus those large tributaries that control local base levels. Loose rock and single-fence dams should be favored and double-fence dams avoided, if effective rock size distribution is in question.

The proposed equation for predicting sediment deposit gradients should be used for determining check dam spacings, if conditions are similar to those at Alkali Creek and the site is within the same physiographic region.

Although the capital investment for prefabricated concrete dams is larger than that for loose-rock structures, they should be considered where high values must be protected (certain campgrounds, for example) and maintenance cannot be performed easily. Lightweight concrete should be avoided and normal-weight concrete used for all structural components.

In general, conversions of gullies to vegetation-lined waterways should be restricted to first- and second-order channels in broad valley bottoms. These waterways must be curved to achieve the necessary increases in length and width and decreases in gradients compared with the original gullies. Potentials for plant growth must also be good, or be improved by measures such as fertilization and irrigation.

Periodic field inspections are imperative to determine maintenance needs. Sometimes, small efforts such as the rearrangement of some rocks in a structure can prevent serious failures.

Study Area

Location

The study area is located on the upper Alkali Creek watershed of the Rifle Ranger District, White River National Forest, 20 mi south of the town of Silt, Colorado. The area is part of the Uinta Basin of the Colorado Plateau Province, and comprises about 1 mi². Elevation rises from 7,600 ft to 8,400 ft.

Climate

Local climate varies widely over the watershed due to differences in elevation and topography. Precipitation was the only climatic factor measured on the study area. The gage network consisted of one recording instrument in the approximate center of the watershed, and seven standard gages distributed over the area. During the period 1962-74, yearly precipitation averaged 18.9 in. Precipitation consisted mainly of rain between May and September, and snow for the remainder of the year (fig. 1). The growing season starts with the beginning of May after most of the snowpack has melted, and ends not later than the last days of August. Precipitation for the growing season averages only 5.6 in, or 30% of the yearly total.

To determine whether the main treatment years fell into a period of normal precipitation, data from four additional nearby Weather Bureau stations were studied. The data reached back to

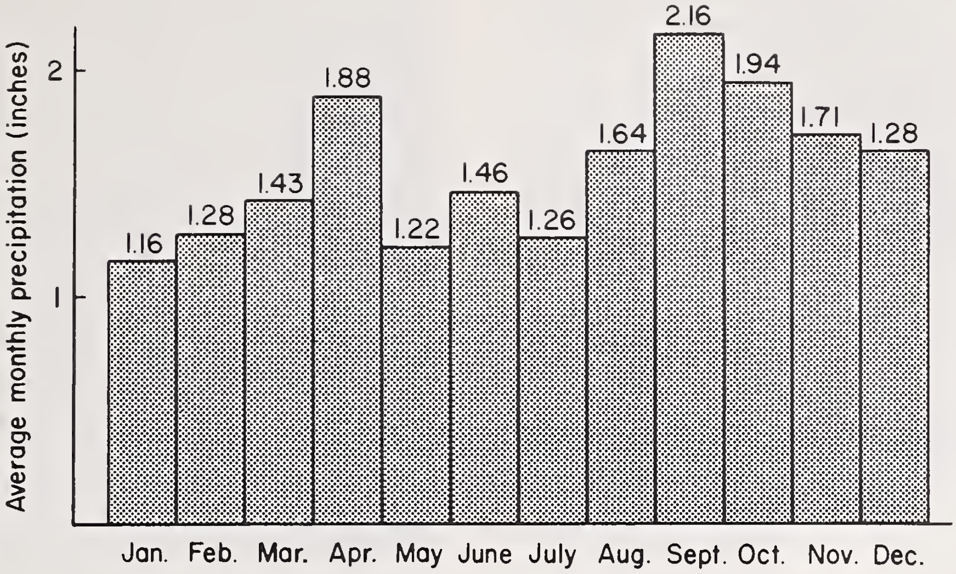

Figure 1.—Average monthly precipitation at Alkali Creek watershed (1962-74).

the turn of the century for most stations. Five-year running means and overall station histories were analyzed. Only the linear regression of Alkali Creek precipitation on the average precipitation of Collbran and Glenwood Springs stations showed a meaningful relationship with a coefficient of determination $\hat{R}^2 = 0.60$. Separation into summer and winter data did not improve the regression.

Based on this regression, the estimated yearly precipitation at Alkali Creek was calculated back to 1904. Because the estimated mean precipitation (18.76 in) did not differ from the actual mean (18.93 in), it was concluded that the main treatment period experienced normal precipitation.

Vegetation

The area is representative of the oakbrush-sagebrush-grasslands of the western slope of the Rocky Mountains in Colorado (fig. 2). Oakbrush

Figure 2.—An aerial view of the project area shows the individual vegetation cover types and extensive gullying of valley bottom and subdrainages in 1961. A road encircles the main valley bottom of the watershed.

mainly occupies the upper parts of north-facing slopes, while sagebrush and grass make up valley bottoms, depressions, and south aspects. Dominant grasses are Kentucky bluegrass and western wheatgrass. Intermediate and crested wheatgrasses have been introduced on some sites. Individual plants of snowberry and serviceberry are scattered over the watershed, and groves of aspen occur in valley bottoms. The distribution of vegetation types is as follows:

Type	Percent total area
Oakbrush	35.0
Aspen	4.3
Grass with sagebrush	46.7
Seeded grass	14.0

Geology and Soils

Rocks of the watershed are of the Tertiary Wasatch formation, which consist chiefly of variegated clay shale and irregular, crudely bedded sandstone. The sandstone varies from fine to coarse-grained and, in places, is strongly calcareous.

The soils are predominantly formed from fine-textured, loose, unconsolidated shales with an admixture of sand from beds of sandstone (Fox and Nishimura 1957), and have a clay texture. Heavy plastic subsoils have developed. Clay content up to 65% has been found. In the mechanical analysis, clay, silt, and sand averaged 52.0%, 27.9% and 20.1%, respectively. The pH value of the soils (1:5 soil-water ratio) averaged 7.8%.

Coarse material, such as gravel or boulders, is not present in the gullies. But boulders derived from the former volcanic cappings of the surrounding mountains are erratically strewn over the watershed, and some talus of coarse debris exists below erosional sandstone escarpments.

Although the regolith is generally rather thick, alluvial deposits in excess of 6-ft depth are found on the main valley bottom. Soil piping is most extensive here. High exchangeable sodium percentage, low gypsum content, fine-textured soils with montmorillonite clay, and a hydraulic head are prerequisite for the formation of the pipes (Heede 1971). The sodium is derived from the shale.

Gully Flows and Sediment Loads

Numerous continuous or discontinuous gullies of varying sizes dissect the bottom lands and the side slopes of the watershed (Heede 1970).

Gully flows were ephemeral during the first 7 treatment years. Flows occurred only during spring snowmelt and at times of exceptionally intense summer storms. Flows of 20 ft^3/sec (cfs) were estimated at the watershed mouth from current meter measurements and velocity head-rod readings in the spillway of a concrete dam. Generally, snowmelt flows peaked early after the melt had begun. Recession flows decreased rapidly but could run for 7 weeks.

Suspended sediment concentrations in the gully flows were not related to flow discharge but to elapsed time and flow duration (Heede 1974). This relationship is determined by the availability of easily removable sediment at the beginning of a flow and its decreasing availability with flow duration.

Grazing History

Alkali Creek watershed is part of the West Divide Creek Cattle Grazing Allotment. Bottom lands and tributary drainages provided grazing since the distant past, as demonstrated by the excavation of a buffalo skull. The watershed also serves as a winter range for elk since the south aspects carry a discontinuous or low snowpack as compared to the north aspects.

It is believed that cattle grazing on the watershed started with settlement along the Colorado River and its tributaries in the 1870's. Local ranchers estimated that, at the turn of the century, 10,000 head of cattle grazed what was later known as the West Divide Creek Allotment, an area comprising about 70 mi^2 of usable open grazing land. To envision the impact of this intensity of grazing on the land, consider that, in 1960, only 2,618 head were permitted. The watershed not only experienced regular grazing by the permitted number of cattle, but also served as an important driveway for domestic animals between the high and the low country.

As early as 1915, permanent camera points were established to document changes. One of the old photographs (fig. 3A) shows that the main gully could have been crossed on horseback or even by a horse-drawn wagon whereas, 35 yr later, it had developed to a depth of about 25 ft (fig. 3B). A drastic increase in bare ground surrounding this gully can be recognized on a 1959 photograph (fig. 3C), 44 yr after the first picture was taken.

Recognizing the pressure on the land, the Forest Service limited grazing to 4,100 head on the allotment in 1918. In the 1930's, the great economic depression prohibited cattle reduction to meet the range carrying capacity as dictated by the drought. The 1949 photograph (fig. 3B)

must be interpreted in this context, and we may surmise that increased gullying, of the magnitude shown by the figure, was the combined effect of drought and overgrazing as well as overuse on the agricultural lands below the watershed. Overuse of the lowlands led to greater incision of the channels which resulted in a lowering of the base level for Alkali Creek.

In 1951, the Secretary of Agriculture ordered a 15% stocking reduction and a 5-yr range improvement program. Range improvement measures had been practiced on the watershed long before, but the work was done sporadically due to lack of funds.

In 1958, the White River National Forest decided to establish the Alkali Creek Watershed Soil and Water Rehabilitation Project. As the first phase, an area of about 880 acres was fenced and cattle excluded.

Treatments

As a second phase of the rehabilitation project, the help of the Rocky Mountain Forest and Range Experiment Station was enlisted in 1960 to test gully control and watershed rehabilitation measures, and to develop new techniques for restoration. Treatment plans were devised, and gullies were treated in 1961 and 1963.

Check Dams

The mainstem and nine tributary gullies were treated by check dams, representing 40% or 2.16 mi of 5.45-mi total gully length on the watershed[4]. In discontinuous gullies, check dam treatments included control of the gully headcuts (Heede 1966). As a routine procedure, a mixture of grass and yellow sweetclover seeds was broadcast on all areas disturbed during construction in the gullies as well as on the road. Seeding was repeated where necessary.

[4] *Mr. Lawrence Forman of the White River National Forest provided invaluable assistance in installing and monitoring structures, and obtaining subsequent runoff data under difficult conditions at critical times.*

Figure 3.—The main gully as photographed in 1915 (A). Note that it can still be crossed by wagon or on horseback (see arrow for location). By 1949, the gully had deepened and the gully side slopes steepened (B). Gully crossing is possible only on foot. By 1959, 44 yr after the first picture was taken, the gully had deepened and widened further (C), and bare ground increased.

The watershed mouth represents the local base level of the watershed, and therefore, a newly designed prefabricated concrete dam was placed there (fig. 4). Design and installation of this key structure are described elsewhere (Heede 1965). All other check dams, a total of 132, were designed of loose rock or a combination of loose rock with mesh wire and steel fenceposts (fig. 5). Six major gully headcuts were treated with loose rock alone. Each structure was individually designed for the installation location (Heede 1966). Basic requirements for the check dam designs were:

1. Design (and construction) of check dams would begin at the gully mouth and proceed upstream.
2. Spillways would accommodate the estimated peak flow of the 1-hr storm having a 25-yr return period and a volume of 1.2 in (Weather Bureau 1961).
3. Freeboards would be at least 2 ft long to protect the gully side slopes at the structure.
4. Check dams would be keyed into the gully bottom as well as the side slopes.
5. Apron and bank protection would be provided for all dams.

Figure 4.—The upstream face of this slab-buttress dam is inclined at an angle of about 10° from the vertical, causing the wall to lean downstream and discharge the water overfall away from the toe of the structure. This is the first runoff, 9 months after installation. Stage is beginning to rise for the daily peak.

Figure 5.—Upstream view of loose rock check dam during second snowmelt runoff season after construction. Effective dam height is 7 ft. Discharge is approximately 12 cfs.

6. Check dams would be installed approximately at the estimated expected upstream toe of the sediment deposits caught by the next downstream dam. The upstream toe of the deposits would be estimated from a rule of thumb: in gullies with gradients $<20\%$, the slope of the expected deposits is 0.7% of the original gully gradient; in gullies with gradients $\geq 20\%$, the coefficient should be reduced to 0.5%.
7. The narrowest possible gully cross section would be selected to save construction materials, if such a section was not more than 50 ft from the estimated toe deposit.

Vegetation-Lined Waterways

Four gullies with a total length of 1,900 ft were converted to vegetation-lined waterways. The treatment represented a new approach to gully management on mountain slopes. In contrast to earlier attempts elsewhere, the new watercourses were not located on the filled gullies but away from them. The cut material derived from the construction of the waterways was used to fill the gullies.

Cut and fill volumes were carefully balanced in the design without requirements for borrow pits or deposition of material outside the gully. This kept the total disturbed area at a minimum, and assured that the waterways were not placed on fills. Before start of construction, the topsoil of the area to be disturbed was removed by tractor with cutting blade and stockpiled at the fringe of the area to be redistributed after construction was finished. The depth of cut for the waterway averaged only 2 ft (including depth of topsoil) to prevent excessive exposure of deeper strata of subsoil.

The surfaces of the filled gullies sloped with the mountainside, but were also inclined toward the new watercourses to prevent water saturation and possible mass movement of the fills before stabilization by a vegetation cover was achieved. The cross sections of the waterways were designed to resemble gentle swales with a bottom width of 12 ft and side slopes not steeper than 5:1. The objective was to attain shallow depths of future flows (two-dimensional flow), large wetted perimeters, large roughness parameters, and low flow velocities, as compared with the original gully flows. The length of the waterways was increased over that of the gullies by an average of 11%, resulting in a respective gradient decrease. This led to additional decreases in flow velocities. The gullies were located on north, south, and southwest aspects.

Plant selection and fertilization were important aspects of the design. Vegetation rehabilitation treatment for the disturbed areas were in two phases. In the first, following construction, a pioneer vegetation was planted that consisted of a mixture of an annual rye grass and yellow sweetclover. In the second phase (second treatment year), a perennial grass cover was achieved (mainly smooth brome and intermediate wheatgrass). This relatively quick cover establishment was made possible by heavy and repeated fertilization with ammonium phosphate (13-39-0) at a rate of 110 lb/acre and triple super phosphate at a rate of 60 lb/acre (fig. 6).

Design details as well as first results, obtained after three growing seasons, were reported earlier (Heede 1968). These results demonstrated that, as compared with untreated gullies, the vegetation-lined waterways had reduced soil losses by 91%. Maintenance work could cease.

Figure 6.—Waterway 6, 4 yr after treatment, shortly after disappearance of the snowpack. Note the dense mat of plants and litter that provided effective armoring against the snowmelt runoff.

Vegetation Management

Vegetation management began with fencing of the area in 1958, followed by cattle exclusion for 8 consecutive years and reduction of grazing for the last 9 years. When installation of the treatments was completed, the access road, temporary roads, and all areas disturbed by construction were repeatedly seeded to grass until a satisfactory vegetative cover was achieved.

A vegetation survey preceded the major treatments, and was repeated 13 yr later. The vegetation cover was stratified into poor, good, and seeded cover by use of aerial photographs. Good cover was indicated by relatively high plant densities, while poor cover areas showed low densities, typified by large numbers of bare soil spots. Oakbrush and aspen covers were excluded from consideration. Poor and good covers consisted primarily of sagebrush and native grasses, respectively. The seeded cover consisted of introduced grasses, plus invaded or regrown sagebrush.

The individual sampling areas covered about 5 acres, approximately 500 x 400 ft in size. All areas were located outside gullies. Sample lines were run at about 50 ft intervals. Along each line, 3/4-in loop measurements were taken at 6-ft intervals from a random starting point. Observations consisted of basal herbaceous hits, plant species, litter, rock, and bare soil which occupied half or more of the loop.

Results

Performance of Check-Dam Treated Gullies

Structural Stability. Rock size distribution in the structures did not follow the contract specifications. It was estimated that large sizes (diameter ≥ 1 ft) made up 80% of the total. Later attempts to break these rock into smaller sizes with a pavement breaker were not successful. Effectiveness of the narrower double-fence dams was reduced most due to large voids caused by lack of smaller rocks, and maintenance was soon required. Loose rock, loose rock wire bound, and single-fence dams were only slightly affected by the poor rock size distribution. Close inspection and maintenance during the first 4 treatment years avoided any structural loss (fig. 7(A), (B)). Practically no maintenance was carried out during the last 7 treatment years. Galvanized wire, steel fenceposts, and rebars used in the dams are still intact (fig. 8(A), (B)).

Maintenance has not yet been required at the prefabricated concrete dam, but the center but-

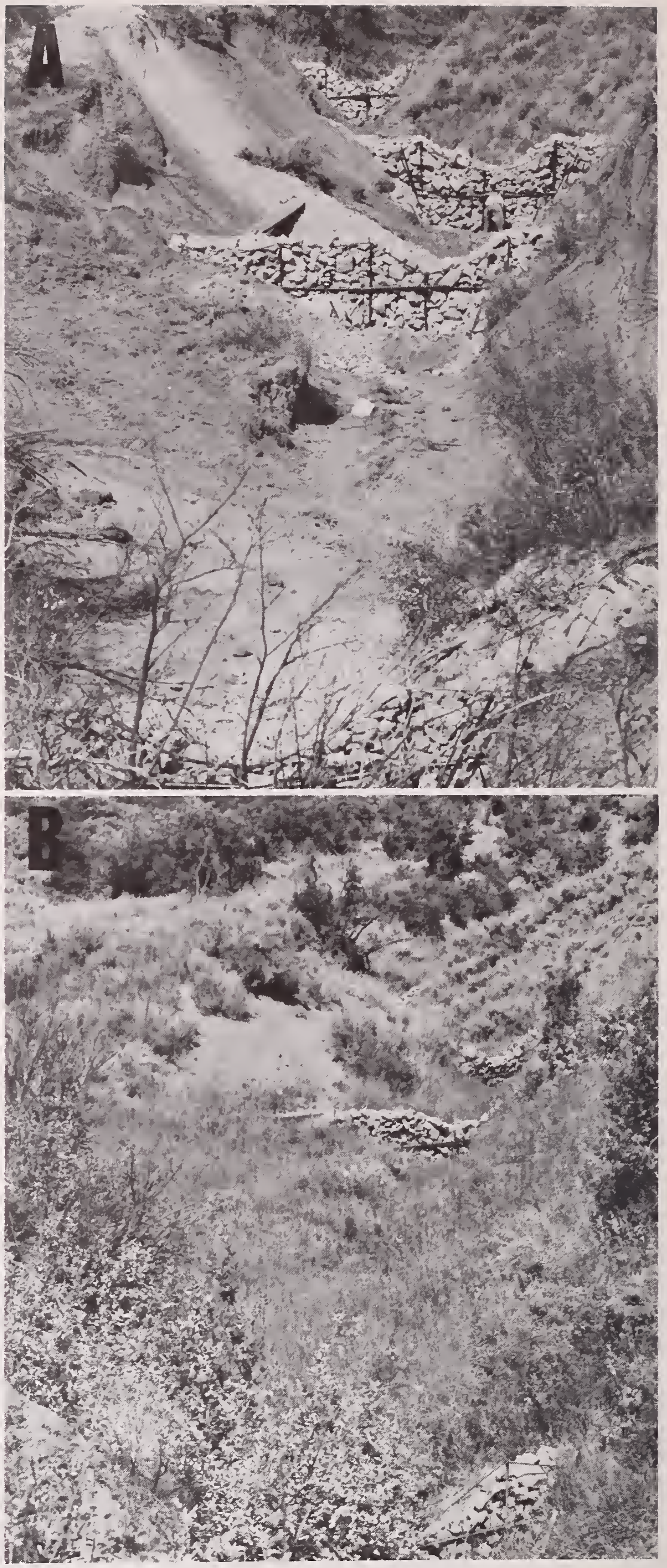

Figure 7.—Upstream view into the headwater reach of the main gully during the last phase of construction (rearrangement of rocks by hand on apron and bank protection work) (A), and 12 yr after treatment (B). The structures are intact. Most channel areas have been invaded by vegetation.

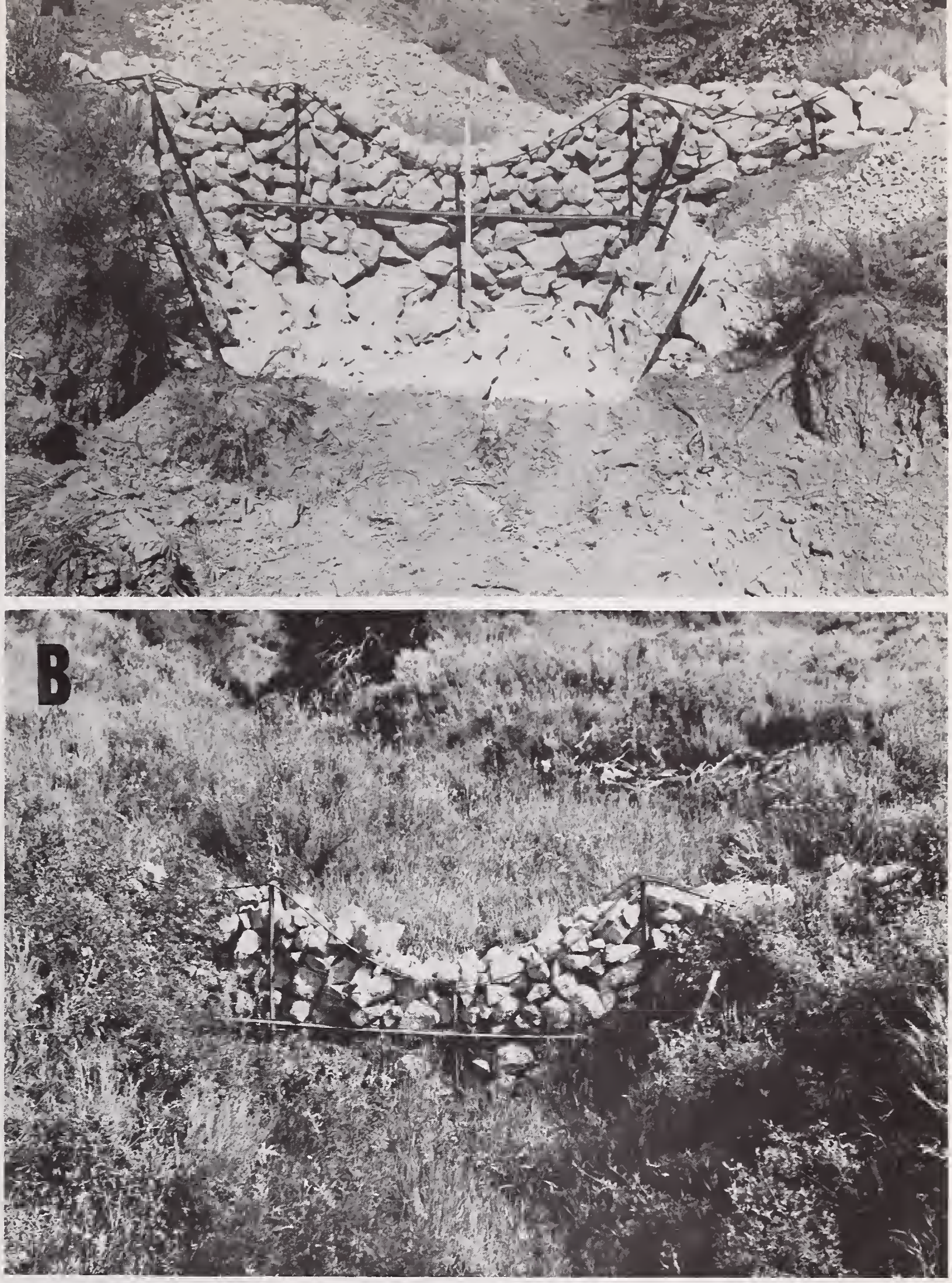

Figure 8.—Upstream view of new double-fence dam (A). Height of rod is 5.5 ft. Twelve yr later (B), vegetation covers the gully bottom and side slopes, and encroaches upon the apron and bank protection work.

tress, manufactured from reinforced lightweight concrete, will eventually require maintenance due to surface flaking. Freeze and thaw actions are mainly responsible; porosity of lightweight concrete is much higher than that of normal-weight concrete. The dam slabs, built of prestressed normal-weight concrete, appear like new.

Flows and suspended sediment concentrations. No streamgaging stations were installed on the watershed. Flows were estimated from current meter and velocity headrod readings, as well as from head of flow measurements at the concrete dam during snowmelt. Suspended sediment was sampled with an integrated hand sampler (HD-48). Newly designed crest gages, described elsewhere (Heede 1967), were installed in all gullies and waterways to give indications of flow occurrences and peaks.

Flow and suspended sediment estimates were based on point measurements. Due to large hourly and daily fluctuations of the melt flows, total water and sediment yields could not be estimated.

In 1970, the seventh year of treatment, the flow converted from ephemeral to perennial, although our analysis showed normal precipitation for the treatment period. Substantial grass cover increases within the gullies, as well as formation of additional alluvial aquifers above the check dams (sediment deposits), are believed to be responsible for the flow conversion. Conversion to perennial flow after a check dam treatment was reported once before (Brown 1963).

Table 1.—Suspended sediment samples from gully flows taken 1, 12 and 13 years after treatment.

Sampling station	Days before (−) and after (+) peak flow (0)			Flow discharge			Sediment concentration			Sediment discharge		
	1964	1975	1976	1964	1975	1976	1964	1975	1976	1964	1975	1976
				.... cfs			.... ppm			.... lbs./s.		
Low reach	−2	−2		8.12	6.34		20,766	1,608		10.60	0.64	
Main gully	−2	−2		8.12	6.00		19,214	2,023		9.81	.75	
		−2			6.71			2,377			.97	
		−2			6.71			1,885			.77	
	0	0		19.42	4.59		13,432	991		16.29	.29	
	0	0		19.42	4.59		13,437	926		16.40	.26	
	0	0		19.42	4.59		13,779	851		16.80	.24	
		0			4.59			839			.24	
		0			4.59			976			.29	
		0			6.36			1,407			.55	
		0			6.36			1,213			.49	
		+1	+1		1.41	0.35		62	250		.0051	0.0079
		+1	+1		1.41	.35		164	246		.0132	.0070
		+2	+2		1.77	1.06		463	85		.04	.0060
		+2	+2		1.41	1.06		585	40		.04	.0031
			+2			1.41			19			.0020
			+2			1.41			23			.0020
			+3			1.41			78			.0060
			+3			1.41			54			.0040
			+3			1.41			99			.0079
			+3			1.41			48			.0040
			+3			1.41			99			.0090
			+3			1.41			66			.0060
	+14			6.71			5,084			2.09		
	+14			6.71			4,916			2.01		
	+14			6.71			4,499			1.90		
	+14			6.71			4,535			1.87		
	+14			6.71			5,220			2.16		
	+14			6.71			4,433			1.83		
	+42			.71			19			.0007		
	+42			.71			38			.0013		
	+42			.71			58			.0022		
	+42			.71			23			.0009		
Low reach	0			7.06			35,706			15.81		
Gully 3	0			7.06			31,864			14.13		
		+2			2.12			2,775			.40	
		+2			2.12			2,625			.37	
		+2			2.12			2,701			.37	
		+2			2.12			2,824			.40	
		+3			1.41			1,462			.11	
		+3			1.41			1,358			.13	
		+3			1.41			1,577			.15	
		+3			1.41			1,325			.13	
		+5	+5		—	.35		961	640		—	.0139
			+5			.35			257			.0051
			+6			.28			132			.0002
			+6			.28			122			.0002
			+6			.28			282			.0004
	+15			.71			12,402			.46		
	+15			.71			12,719			.49		

At the beginning of the treatment period, suspended sediment concentrations were very high. Concentrations of 35,700 ppm were sampled at a flow rate of 7 cfs. Table 1 shows periodic posttreatment snowmelt flow and suspended sediment data. Sediment samples were analyzed for selected time intervals relative to peak flow, because concentrations of the suspended load decreased with flow duration. The last flows of the snowmelt season picked up part of the sediment deposits from bars as well as catch basins above dams. Thus, one of the expected benefits from the check dam treatments, decrease of gully bank height, would not be attained in all cases.

Due to large amounts of clay and silt in the load, close to true suspension existed (table 2). As could be expected, bedload contributed mainly to the sediment accumulations above the check dams. While sand was only a minor constituent of the suspended load (table 3), it made up a large portion of the deposits (34.5% based on 11 samples taken at different depths from deposits above 5 check dams). Gravel made up only 1.7% of the deposits.

Sediment Accumulations. One half of all gullies with check dams, or 44% of all dams, never experienced sufficient flows to carry loads substantial enough to accumulate deposits above the structures. This left 75 check dams with sediment deposits that totaled 69,260 ft³. Of these, only 36 dams were completely filled, leaving a potential for future accumulations of 15,000 ft³ at the partially filled dams. An equation for a truncated triangular prism was used for the volume calculations.

Table 2.—Suspended sediment concentrations[1] in flows with different regimes.

Location at dam M/1	April 28, 1964 Flow discharge	April 28, 1964 Sediment concentration	April 26, 1975 Flow discharge	April 26, 1975 Sediment concentration	April 14, 1976 Flow discharge	April 14, 1976 Sediment concentration
	cfs	*ppm*	*cfs*	*ppm*	*cfs*	*ppm*
Inflow to catch basin	6.7	4,433	4.5	926	1.4	66
Inside catch basin		5,220		976		
Overfall	6.6	4,535	4.5	991	1.3	48
20 ft downstream	6.6	4,499	4.5	851	1.3	54

[1]Average particle size distribution was 33.5, 60.3 and 6.2% for clay, silt and sand, respectively. All sediment samples on a given day taken within 30 min time interval.

Table 3.—Net erosion in vegetation-lined waterways.

Waterway no.	Net erosion 1963-65	1965-75	1963-75
	ft/lin ft/yr		
6	−1.88	0.54	−0.02
9	−.46	−.17	−.22
16	2.53	.63	.95
18	1.05	.74	.79
Aver.	.31	.43	.37

The sediment deposits above the dams covered extensive gully segments, averaging 65% of total treated gully length. Upstream sediment wedges extended up to 360 ft from the structures.

The ratio between sediment deposit gradient and gully gradient, which had been used to determine check dam spacings, could not be verified for dams with either full or partial sediment accumulations.

Woolhiser and Lenz (1965) have developed an equation for the prediction of sediment deposit gradients above check dams. It presents the deposit gradient (S_{up}) as a function of original channel slope (S_{uo}), channel width at spillway elevation (B) and height of dam (H):

$$S_{up} = a_1 S_{uo}^{b_1} (a_2 + a_3 b_a + a_4 H)^{b_2} \qquad [1]$$

where a_1, a_2, a_3, a_4, b_1, and b_2 represent regression coefficients.

The equation was developed from field data of gully control structures in Wisconsin and tested on a gully treatment in California. In both areas, the dams were older than 20 yr, as contrasted with 12 yr for the Alkali Creek dams. The structures in California were much higher (mean heights 17.2 ft, maximum 35.0 ft) than those at Alkali Creek (mean height 3.9 ft, maximum 7.0 ft). In Wisconsin, mean structural height was similar (4.4 ft) and maximum height larger (11.0 ft). Sugio (1966) found that at least 20 yr were required to attain equilibrium at two large dams (H = 150 and 22 ft). One cannot rule out, however, that small dams may require less time to reach equilibrium than larger ones.

Application of the equation to the Alkali Creek data resulted in a coefficient of determination ($\hat{R}^2$) of only 47%. When the deposit gradients of the filled dams were linearly regressed on the original gully gradients (fig. 9), a very simplified form of equation [1] resulted with $\hat{R}^2 = 0.73$:

$$S_p = 0.72 + 0.28 S_o \qquad [2]$$

Figure 9.—The relationship between original gully and sediment deposit gradients at Alkali Creek watershed.

If several channel segments with different gradients existed above the dam, the segment with greatest length and/or judged to have overriding influence on the sedimentation process, was used as the original gradient in design as well as in this equation. Original channel slopes ranged between 2% and 29%.

When the deposit gradients of the partially filled dams were regressed on the original gully gradients, the value of $\hat{R}^2$ was only 50%. This suggests that equilibrium conditions had not yet been reached at these structures.

Gully Stabilization. Check dams stabilized and raised the local base levels of the gullies. This prevented further gully downcutting and made possible toe stabilization of gully banks. Since the dams have effective heights up to 7 ft, substantial decreases in gully depth resulted. Combined with bank toe stabilization, this led to gentler gully side slopes which in turn allowed vegetation to become established (fig. 10(A), (B)). Gully bank stabilization appears to have followed a pattern, well known for hill slope development, of convex rounding of gully brinks (see fig. 7(B)), and concave rounding of bank toes (fig. 10(B)). Carson and Kirkby (1972) claim that this is the result of transport-limited processes, and stems from a combination of weathering, creep, and rainsplash. Especially where the newly shaped banks were invaded by a vegetative cover, a much more stable landform exists now compared with original raw gully banks.

In some cases, channel scarps developed upstream from the sediment deposition wedge. (Dam spacings calculated by use of equation [2] are closer than those applied to the treatment.) The scarps were caused by pronounced breaks in gradients (nickpoints) between deposition slope and original channel slope. But not one structure was endangered 12 yr after treatment. The luxuriant growth of channel vegetation (fig. 11) almost stopped the upstream advance of the scarps.

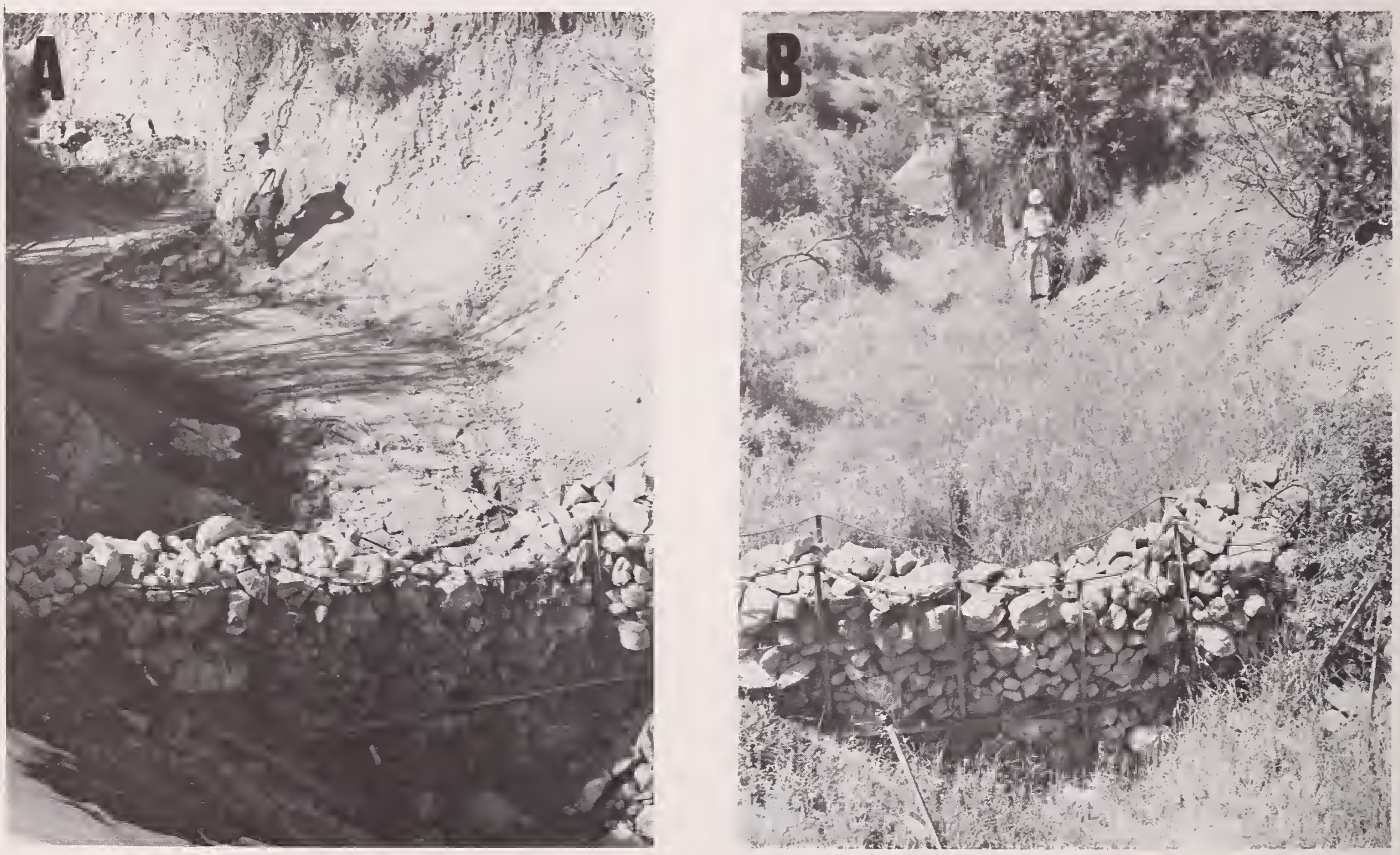

Figure 10.—This double-fence dam, installed in the upper main gully, has an effective height of 6.5 ft. It filled with sediment during the first snowmelt season after construction (A). Note that some of the deposits were removed by recession flows. A repeat photo 10 yr later shows vegetation invasion on gully bottom, at check dam, and toe of gully side slopes, as well as a pronounced decrease in slope gradient of gully walls in fore- and background.

Figure 11.—Channel scarp, 1.7 ft deep in a gully with no structural treatment, is nearly hidden by a dense mat of vegetation. The vegetation substantially reduces the upstream advance of the scarp.

If bed scarp spacings and depths were compared between gullies with and without check dams, another treatment effect became apparent:

Dam use	Average spacing	Average depth
	.... *ft*	
With check dams	218.4	1.23
Without check dams	60.7	1.60

The differences in spacing and depth were statistically significant. Both groups of gullies were comparable since they had similar dimensions (length, depth, width).

Performance of Waterways

Rills formed in some reaches of the waterways during the first snowmelt runoff when the vegetation cover was still sparse. To prevent the formation of continuous rills, submerged burlap strips were installed at a spacing of 5 ft in these reaches, which amounted to approximately 35% of the total waterway length (Heede 1975a). The burlap treatment was successful with the exception of one waterway (No. 18). On this watershed, the burlap strips rotted 5 to 6 yr after installation and became ineffective. A continuous rill developed, in places up to 0.5 ft deep, where a narrow valley bottom restricted the width of the waterway. Waterway 18 had the largest annual net erosion rate during the last 10 treatment years (table 3). It requires immediate maintenance by armoring the bottom with loose rock.

Table 4.—Net erosion in gullies without structural treatments.

Gully no.	Net erosion 1963-65	1965-75	1963-75
	.... ft^3/lin ft/yr		
5	7.03	0.85	2.28
12	2.17	1.37	1.60
15	2.84	.25	.99
19	.72	.34	.40
Aver.	3.19	.70	1.32

For the compilation of table 3, the data for the period 1963-65 were reduced to those cross sections that could be safely reestablished in 1975, about 90% of the original. Thus both periods could be compared. Net erosion is erosion minus deposition as determined from the topographic surveys.

Table 3 shows that waterway 9 had no net erosion during its total lifetime of 12 yr (fig. 12). Although it is the steepest of all (average gradient = 17.4%) and located on a south aspect (such as waterway 6), no rills developed and the vegetation cover appears healthy and dense. This is also the case on waterway 6. Waterway 16 had a north exposure, while 18 is exposed toward the northeast.

To assess the overall performance of the waterways, a comparison of average annual net erosion rates in ft^3/lin ft/yr showed a rate of 0.37 for waterways against 1.32 for gullies not structurally treated.

So far, the waterways have experienced less than 1/3 the net erosion of gullies not structurally treated. We know now that waterway 18 should not have been constructed. If this waterway is omitted from the calculations, the average net erosion rate of the remaining three waterways drops to 0.24 ft^3/lin ft/yr, less than 1/5 that of the comparison gullies.

Figure 12.—Waterway 9, 12 yr after conversion of the gully once located on the left margin of the seeded area. View is upstream.

and location of outside gullies within 1 mi of the project area and within the Alkali Creek system. Each group ("inside" and "outside") consisted of four gullies with a total length of about 3,500 ft. Stream orders (Strahler's method) and increases in gully area per linear foot of gully were as follows:

Gully No.	Stream order	Relative increase in area
"Inside"		
2	2	1.55
5	2	2.06
14	3	.90
17	3	1.29
	Average	1.45
"Outside"		
I	2	5.75
II	2	7.27
III	4	2.35
IV	2	3.10
	Average	4.62

Improvement of Gullies That Were Not Structurally Treated

Gullies that were not structurally treated, used for comparison with the waterways, were surveyed three times: once, shortly before the main treatment started, secondly, after 3 or 4 growing seasons, and thirdly, 10 yr thereafter (table 4).

The main finding was that, even without check dam treatments, net gully erosion decreased consistently in all gullies by a substantial average volume of 78%. As stated in previous chapters, normal precipitation fell during the total period and only one large storm hit the area. This occurred during the second period when average net erosion dropped from 3.19 to 0.70 ft^3/lin ft/yr. It was necessary, therefore, to determine whether erosion decreased also in similar untreated gullies outside the project area.

Aerial photographs (scales 1:11,250 and 1:13,300) taken before start of the main treatment and 14 yr later were examined. Criteria for the selection of the gullies were: sufficient size to allow channel width and length measurements on the photographs; comparability of size between gullies inside and outside the project area;

Although increases in gully area do not necessarily correspond with erosion, the data agree with casual observations that erosion is much more active in the outside gullies. On the average, these widened 3 times as much as the inside gullies that were not structurally treated. The latter benefited from intensified cattle grazing management (vegetation cover improvement, reduction of surface disturbance by cattle trampling, etc.) and grass plantings on some sites. In addition, a decisive factor in the stabilization was the maintenance or increase of local base levels caused by deposition behind check dams in the structurally controlled gullies. The finding that improved vegetative cover, coupled with structural treatment of part of the gully system, substantially decreases erosion in gullies that are not structurally treated indicates that not all gullies of a watershed require structures.

At Alkali Creek, two-thirds of the treated second-order streams did not accumulate any measurable quantities of sediment above the dams, and in the remaining third, the structures were only partially filled. Confining check dam installation to the fourth- and third-order streams at Alkali Creek would have saved 30% of the treatment costs.

Vegetative Cover

Hydrologic Characteristics. Type and quality of the vegetative cover influence infiltration rates, which in turn influence erosion rates. Thus the hydrologic conditions of a site depend to a large degree on the plant cover. Dortignac and Love (1961) found rather rapid recovery of infiltration rates in the Front Range after protection from cattle grazing (6 and 13 yr of protection on pine-grassland and on grassland, respectively), while in the Piceance Basin, removal of vegetation and litter reduced infiltration rates from 1.97 to 3.94 in/hr to about 0.79 in/hr (Meiman 1975).

The oakbrush sites on Alkali Creek watershed had dark organic surface layers with depths ranging from 9 to 22 in; on the other sites, the organic surface layer varied from zero to 10 in. The soil surfaces below the oakbrush stands were covered by humus, litter, and herbaceous vegetation, predominantly Thurber fescue. Virtually no humus and lesser amounts of litter occurred beneath the other vegetation types. There was no evidence of concentrated surface runoff under oakbrush, and infiltration rates appeared to be high. In terms of surface runoff and erosion, it was concluded that oakbrush sites represented the best hydrologic condition on the watershed.

In contrast, infiltration rates were low on sagebrush sites. Except for exposed shale beds, the sagebrush sites on hillslopes were the most erosive. These sites were characterized by extensive rilling, pedestaled plants, and little herbaceous cover.

Changes. Ground cover (vegetation, litter, and rocks) increased substantially and bare soil decreased in all but one area from 1963 to 1975 (table 5). Increases in ground cover were largest in areas that were sparsely vegetated at the start of the study. Vegetation increases were responsible for the increase in ground cover under all conditions; litter added to the cover under poor conditions and in one seeded area (table 6). With the exception of one area, sagebrush increased. On the average, the perennial grass and forb cover decreased under all conditions (table 7). Annual grasses and forbs increased on the nonseeded areas and decreased on the seeded areas. Except for phosphorus, the soils were found to contain sufficient amounts of elements essential for the growth of grasses.

Observation and photo comparisons showed that vegetative cover increased greatly within all gullies, whether structurally treated or not (figs. 13(A) and (B), 14). The species most responsible for the increased vegetative cover belong to the Juncaceae and Salicaceae families. This indicates an increase in available water within the gullies, since these families are true phreatophytes and require substantial amounts of water. Vegetation also invaded the gully bank protection and apron structures where alluvial and colluvial materials were deposited (fig. 15).

Table 5.—Ground cover and bare soil changes (percent of total area).

	Ground cover			Bare soil		
Area	1963	1975	Change	1963	1975	Change
Poor vegetation cover (not seeded)						
2	41.4	67.9	26.5	58.6	32.1	−26.5
3	54.7	75.8	21.1	45.3	24.2	−21.1
Aver.	48.0	71.8	23.8	52.0	28.2	−23.8
Good vegetation cover (not seeded)						
1	86.7	87.9	1.2	13.3	12.1	−1.2
4	90.9	96.9	6.0	9.1	3.1	−6.0
6	93.5	98.7	5.2	6.5	1.3	−5.2
Aver.	90.4	94.5	4.1	9.6	5.5	−4.1
Seeded cover						
5	51.0	81.0	30.0	49.0	19.0	−30.0
7	77.8	76.5	− 1.3	22.2	23.5	1.3
Aver.	64.4	78.8	14.4	35.6	21.2	−14.4
Aver. of all areas						
Total						
Aver.	70.9	83.5	12.6	29.1	16.5	−12.6

Table 6.—Vegetation, litter and rock cover changes (percent of total area).

	Vegetation			Litter			Rock		
Area	1963	1975	Change	1963	1975	Change	1963	1975	Change
Poor vegetation cover (not seeded)									
2	0.7	7.8	7.1	40.8	60.1	19.3	0	0	0
3	2.5	8.1	5.6	51.2	67.7	16.5	1.0	0	−1.0
Aver.	1.6	7.9	6.3	46.0	63.9	17.9	.5	0	− .5
Good vegetation cover (not seeded)									
1	4.5	10.5	6.0	82.2	77.4	−4.8	0	0	0
4	3.8	14.2	10.4	87.1	82.7	−4.4	0	0	0
6	4.8	12.9	8.1	88.7	85.8	−2.9	0	0	0
Aver.	4.4	12.5	8.1	86.0	82.0	−4.0	0	0	0
Seeded cover									
5	3.8	13.0	9.2	47.2	68.0	20.8	0	0	0
7	4.5	19.7	15.2	72.2	55.9	−16.3	1.1	.9	−.2
Aver.	4.2	16.4	12.2	59.7	61.9	2.2	.5	.4	−.1
Aver. of all areas									
Total									
Aver.	3.5	12.3	8.8	67.1	71.1	4.0	.3	.1	−.2

Annual grasses and forbs contributed to vegetation cover increases within and outside of the channels (see fig. 13(B)). Annuals normally were not present during the crucial spring snowmelt period and did not add to gully surface protection although their dead roots and above-ground residues may have provided some protection. In contrast, perennial grasses formed mats of dead plant material on gully bottoms and in waterways, providing considerable stability (see fig. 6).

Table 7.—Vegetation cover changes (percent of total vegetation).

Area	Annual grasses & forbs 1963	Annual grasses & forbs 1975	Annual grasses & forbs Change	Perennial grasses & forbs 1963	Perennial grasses & forbs 1975	Perennial grasses & forbs Change	Shrubs (dominantly sagebrush) 1963	Shrubs (dominantly sagebrush) 1975	Shrubs (dominantly sagebrush) Change
Poor vegetation cover (not seeded)									
2	0	2.6	2.6	100.0	53.2	−46.8	0	44.2	44.2
3	0	0.6	0.6	92.0	92.6	0.6	8.0	6.8	−1.2
Aver.	0	1.6	1.6	96.0	72.9	−23.1	4.0	25.5	21.5
Good vegetation cover (not seeded)									
1	0	15.7	15.7	100.0	53.3	−46.7	0	31.0	31.0
4	0	25.3	25.3	100.0	42.1	−57.9	0	32.6	32.6
6	0	26.4	26.4	96.9	62.4	−34.5	3.1	11.2	8.1
Aver.	0	22.5	22.5	99.0	52.6	−46.4	1.0	24.9	23.9
Seeded cover									
5	2.7	1.2	−1.5	97.3	98.8	1.5	0	0	0
7	0	.5	.5	100.0	84.8	−15.2	0	14.7	14.7
Aver.	1.3	.8	−.5	98.7	91.8	−6.9	0	7.4	7.4
Aver. of all areas									
Total									
Aver.	.3	10.6	10.3	98.2	70.6	−27.6	1.5	18.8	17.3

Figure 13.—The main gully after treatment in 1963 (A). Note the raw bottom and many raw gully side slopes. Thirteen years later (B), grasses and willows cover the bed, and herbaceous vegetation is invading the side slopes.

Figure 14.—Grass forms a dense mat on the bottom of the main gully and is invading bare gully side slopes (curved arrow). The toe of the slope is indicated by a straight arrow.

Figure 15.—Upstream view of a double-fence check dam, 14 yr after construction. The apron, as well as the bank protection works, is nearly fully overgrown by herbaceous vegetation and brush.

Literature Cited

Brown, J. B. 1963. The role of geology in a unified conservation program, Flat Top Ranch, Basque County, Texas. Baylor. Geol. Stud. Bull. No. 5, Baylor Univ., Waco, Texas, 29 p.

Carson, M. A., and M. J. Kirkby. 1972. Hillslope form and process. Cambridge Univ. Press, London, 475 p.

Dortignac, E. J., and L. D. Love. 1961. Infiltration studies on ponderosa pine ranges in Colorado. U.S. Dep. Agric., For. Serv., Rocky Mt. For. and Range Exp. Stn., Stn. Pap. 59, 34 p.

Fox, C. J., and J. Y. Nishimura. 1957. Soil survey report of the Alkali Creek watershed area. U.S. Forest Serv. Reg. 2, Denver, Colo., 43 p.

Heede, Burchard H. 1965. Multipurpose prefabricated concrete check dam. U.S. For. Serv. Res. Pap. RM-12, 16 p.

Heede, Burchard H. 1966. Design, construction and cost of rock check dams. U.S. For. Serv. Res. Pap. RM-20, 24 p.

Heede, Burchard H. 1967. The fusion of discontinuous gullies: A case study. Int. Assoc. Sci. Hydrol. Bull. 12:42-50.

Heede, Burchard H. 1968. Conversion of gullies to vegetation-lined waterways on mountain slopes. USDA For. Serv. Res. Pap. RM-40, 11 p.

Heede, Burchard H. 1970. Morphology of gullies in the Colorado Rocky Mountains. Int. Assoc. Sci. Hydrol. Bull. 15:79-89.

Heede, Burchard H. 1971. Characteristics and processes of soil piping in gullies. USDA For. Serv. Res. Pap. RM-68, 15 p.

Heede, Burchard H. 1974. Stages of development of gullies in Western United States of America. Z. Geomorphol. 18(3):260-271.

Heede, Burchard H. 1975a. Submerged burlap strips aided rehabilitation of disturbed semiarid sites in Colorado and New Mexico. USDA For. Serv. Research Note RM-302, 8 p.

Meiman, James R. 1975. Infiltration studies in the Piceance Basin, Colorado. Thorne Ecol. Inst., Tech. Publ. 12, 42 p. Boulder, Colo.

Sugio, Sutesaburo. 1966. Channel gradients above gully-control structures. Proc. Amer. Soc. Civil Eng. HY1:108-120.

Weather Bureau, U.S. Department of Commerce. 1961. Rainfall frequency atlas of the United States for durations from 30 minutes to 24 hours and return periods from 1 to 100 years. Tech. Pap. 40, Washington, D.C. 115 pages.

Woolhiser, Davis A. and Arno T. Lenz. 1965. Channel gradients above gully-control structures. Proc. Amer. Soc. Civil Eng. 91 (HY3):165-187.

Common and botanical names of plants mentioned

Aspen	*Populus tremuloides* Michx.
Bentgrass, Canada	*Calamagrostis canadensis* (Michx.) Beauv.
Bluegrass, Kentucky	*Poa pratensis L.*
Brome, smooth	*Bromus inermis* Leyss.
Fescue, Thurber	*Festuca thurberi* Vasey
New Mexican locust	*Robinia neomexicana* Gray
Oakbrush	*Guercus gambelii* Nutt.
Rush family	*Luncaceae*
Rye grass	*Lolium* sp (annual species)
Sagebrush, big	*Artemisia tridentata* Nutt.
Serviceberry	*Amelanchior* spp.
Snowberry	*Symphoricarpos* spp.
Sweetclover, yellow	*Melilotus officinalis* (L.) Lam.
Wheatgrass, crested	*Agropyron desertorum* (Fisch.) Schult.
Wheatgrass, intermediate	*Agropyron intermedium* (Host) Beauv.
Wheatgrass, western	*Agropyron smithii* Rydb.
Willow family	*Salicaceae*

Agriculture—CSU, Fort Collins

Heede, Burchard H. 1977. Case study of a watershed rehabilitation project: Alkali Creek, Colorado. USDA For. Serv. Res. Pap. RM-189, 18 p. Rocky Mt. For. and Range Exp. Stn., Fort Collins, Colo. 80521.

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Keywords: Watershed restoration, vegetation rehabilitation, gully control, check dams, vegetation-lined waterways.

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